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PERFORMANCE COMPARISON BETWEEN LOCALLY DEVELOPED AERATORS AND ITS EFFECTS ON CATFISH EFFLUENT

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Abstract: Aerators had being used to enhance dissolved oxygen and important to increase stock density and is widely used in fish culture system. Catfish production is one of the largest segments of fish culture in Nigeria. However, catfish effluents, which usually pollute the environment, need to be controlled. The study was to compare the effectiveness of the two aerators in term of dissolved oxygen and reduction of concentration of catfish effluent. The volume of catfish effluent was collected into two basins (A and B) and diluted at given ratios. The paddle–wheel and Spiral aerators were installed in the basins respectively. Aerators performance evaluation was conducted using unsteady state test. Physicochemical properties of water sampled from the tested ponds were determined in accordance with the American Public Health Association standards. The results indicated that spiral aerator performed better that paddle–wheel aerator because it achieved higher overall oxygen–transfer coefficient, standard oxygen transfer rate and standard aerator efficiency at the same volume of water, speed, power and depth of operation; it is also performance better that paddle–wheel aerator on catfish effluent reduction in the same environmental conditions. Hence, blade configuration is the main factor responsible to difference in their performance.
Keywords: aerators, catfish, dissolved oxygen, effluent, performance

1. INTRODUCTION

It has been noted that recent trends all over the world point to a decline in the quantity of fish landing from sea and is an indicator that fish stocks from capture fishery is not enough to feed human population [1]. Aquaculture therefore remains the only visible alternative for increasing fish production in order to meet the protein need for human consumption.

Catfish production is one of the largest segments of fish culture in Nigeria [2]. The catfish industry plays a very important role in aquaculture industry as the largest segment of aquaculture in Nigeria [3]. Despite the importance of catfish, its effluent has being proved as source of water pollution [4]. However, catfish effluents, which usually pollute the environment, need to be controlled. [5] Highlighted that constructed wastewater treatment wetlands can be used to treat wastewater from different sources like:

- Sewage (from small communities, individual homes, farms, businesses)
- Municipal wastewater
- Septic tanks
- Storm water
- Agricultural wastewater (including livestock waste, runoff, and drainage water).

The uses of biological method (wetland) for catfish effluent control have disadvantages such as [5]:

- it requires a large land area compared to conventional mechanical treatment processes.
- the removal of BOD, COD, and nitrogen in wetlands are continuously renewable processes. The phosphorus, metals, and some persistent organics removed in the system are bound in the wetland sediments and accumulate over time.
- in cold climates the low winter water temperatures reduce the rate of removal for BOD, NH3, and NO3. An increased detention time can compensate for these reduced rates but the increased wetland size in extremely cold climates may not be cost effective or technically possible. To be successful with any aquatic environment supporting fish, fish culture must know to achieve and maintain a suitable aquatic environment. A practicing commercial fish farm must having aeration devices and the knowledge `of, when and how to use them. Aeration can be defined as the process of adding air or oxygen to a mass of water either by natural means or artificially. Dissolved oxygen (DO) is one of the limiting environmental factors that effects fish feeding, growth and metabolism (Boyd 2001). A major problem in catfish farming is the low concentrations of dissolved oxygen (DO) which result from high fish stocking and feeding rates necessary to assure profitability [7–8]. Aeration can remove certain dissolved gasses and minerals through oxidation [9

–10]. Paddle–wheel and Spiral aerators were commonly used in fish culture and form the major capital cost item in the farm. Aerators had being used to enhance dissolved oxygen which is important to increase stock density, growth, improvement in fish yield and is widely used in fish culture system. They are used to increase contact surface of water with air thereby increasing the area through which oxygen is absorbed by the water and to create a circular movement of the pond water.

The following advantages were highlighted by [4, 6, 11–12] are as follows:

- It facilitates the volatilization of undesirable gases such as N_2, NH_3, CH_4 and H_2S, hence it reduces their concentration.
- It accelerates the decomposition and mineralization of organic matter in water and soil
- It diminishes the possible stratification of DO and temperature in the pond water.
- It reduces fish mortality when oxygen is limiting factor
- It enhances fish reproduction.
- It may be an effective sediment management tool in wastewater ponds where a significant portion of sediments are organic.
- To prevent eutrophication

[13–14] reported that, low dissolved–oxygen concentration was recognized as the causes of stress, poor appetite, slow growth disease susceptibility and mortality in aquatic animals. It is generally accepted that the minimum daily dissolved–oxygen concentration in pond culture systems should be above 3 mg L–1 for better feed consumption and growth. Paddle–wheel aerator had been developed with local made materials and its performance evaluation and its effects on catfish effluent had been assessed in Nigeria [9, 15]. This study was to compare between the performance of the developed Paddle–Wheel and Spiral aerators and its effects on catfish effluent in Lagos, Nigeria.

2. MATERIALS AND METHODS

This study was carried out at Fish Farms situated closely to Lagos State Polytechnics, Ikorodu in Lagos State, Nigeria. The experiment of this research was done to determine the more dissolved Oxygen between Paddle–wheel and Spiral aerators in basin water without fish and its effects on catfish effluent reduction.

Factors of study are:

- Paddle–wheel aerator and Spiral Aerator of the same power rating and speed;
- Two circular basins water with the same areas and equal volume of water;
- Two circular basins water with the same equal volume of catfish effluent and the source;
- The two aerators were supported and immersed in water with equal depth.

Aeration Test

The aerator performance was conducted using Non–steady–state aeration test. The test basin was filled to the appropriate depth with water from a tap. Enough Cobalt Chloride and Sodium Sulphite were provided in the test basin and mixed by running the aerator. The masses of Cobalt Chloride and Sodium Sulphite used per cubic metres are presented in Table 2.2. The aerator shaft was 105cm above the floor of the aerator test basin (plate 3). Oxygen–transfer tests were conducted in basin. After maintain DO between 0.0 – 0.1 mg .L for about 5 minutes, the paddle wheel aerator and spiral aerators were run and dissolved oxygen(C_m) was taken at two minutes interval until DO increased from 0 % saturation to at least 90 % saturation.

This prototype aerators operation performance were powered throughout by 0.75KW (1hp) electric motor at 881rpm at various depth range from 16cm to 30 cm and volume range of 1m^3 to 8m^3 at 1m^3 interval this was to determine the optimum uniformity effectiveness of the machine in transmitting dissolved oxygen in the water over two minutes interval. The DO concentrations at saturation (Cs) for water in the aerator test basin were computed for the ambient water temperature and barometric pressure at 15cm depth with the initial dissolved oxygen (C_s) 6.65mg/l and water temperature at 28.8^{0}C and barometric pressure at 758.8mmHg using a polarographic DO meter, thermometer and aneroid barometer respectively.

A polarographic DO meter was used to measure DO concentrations (DO_m) at three places in the basin for at ten equal time intervals while the aerator raised the DO concentration from less than 10% of saturation to about 90% of saturation. The mass oxygen–transfer coefficient at the test temperature (K_La) was calculated as the slope of the regression line for the natural logarithm of the DO deficit ($C_s – C_m$) relative to time between 10% and 70% saturation. The K_La was determined for each sampling point. The K_L a was corrected to 20^{0}C by

The overall oxygen–transfer coefficient with the following equation:

$$K_La = \frac{\ln DO_1 - \ln DO_2}{(t_1 - t_2)/60} \quad (1)$$

where: KLa = overall oxygen–transfer coefficient (hour–); in = natural logarithm; OD_1 = oxygen deficit at t_1 (ppm.); OD_2 = oxygen deficit at t_2 (ppm.); t_l = time 1 (minute); t_2 = time 2 (minute).

$$(K_La)_{20} = K_La \times 1.024^{20-T} \quad (2)$$

The standard oxygen transfer rate (SOTR) and the standard aeration efficiency (SAE) were used to determined the aerator performance:

$$SORT = K_LaT(kO_2)/m^3(1x10^{-3}kg/g) \quad (3)$$

$$SAE \quad = SORT \ /P \quad (4)$$

where: K_{La}= Oxygen transfer coefficient, T =Temperature (°C), P = Power (kW)

Source of Materials and Sample Preparation

Catfish effluents samples were collected from Fish Farms situated closely to Lagos State Polytechnics, Ikorodu in Lagos State, Nigeria. Figure.1 depicts the sampling site at Ikorodu. Plate .1 and 2 shows the paddle wheel and Spiral aerators locally developed for wastewater quality improvement. The experiment made of two aerator test basins (A and B), each contained 1m^3 volume of mixture of untreated catfish effluents and volume water at given dilution ratio (d_{r1}, d_{r2}, d_{r3}, d_{r4}, and d_{r5}) at 1:4 (05), 1:9 (10), 1:14 (15), 1:19 (20) and 1:24 (25) respectively.

Experimental Methods

Both the aerators (Paddle wheel and Spiral aerator machines) were powered by one horse power motor (0.75KW), with six paddles which was installed on the plastic tank A, while plastic tank B, was installed with spiral aerator. The aerators were run for two hours. The required water qualities for both the tanks were determined and analyzed for two hours at thirty minutes interval for three days (designated as T_1, T_2, and T_3) respectively. Physical and chemical properties analysis which included Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Total Ammonia (TNH_3), Nitrite (NO_2), which were analyzed in accordance to the [16] standard.

3. MEASUREMENTS

- **Nitrogen, Nitrite, Nitrate and Ammonia**: 100ml of filtered water sample was collected in Kjeldahl flask fitted with distillation unit. 1g of Magnesium oxide (MgO) was added and distillation started; 25ml of distilled was collected. 1g of devards alloy was added to the remaining volume of the flask and distillation started again. 25ml of distilled was taken into two separate Nessler tubes and 0.5ml Nessler reagent was added to each tube. The mixed solution started developing colour. This colour after 10–15 minutes was matched against colour discs of a Nesslenizer (BDH Nesslenizer). Nitrogen content (mg/l) is expressed as follows:
  N, NO_2, NO_3 and NH_3 (mg/l) = number of matching division of the standard disc × 100 × 0.01 [16].
- **Phosphorus (mg/l):** 50ml of filtered water sample was put in a Nessler tube. 2ml of sulphomolybdic acid and 5 drops of stannous chloride solution were added. The mixtures were mixed thoroughly. The developed blue colour after 3–4 minutes was compared with Nesslenizer standard colour discs. The phosphate content (P_20_5) in mg/l is expressed as follows:
  Phosphate (mg/l) = disc reading for 50mm × 2 × 0.01 [16].
- **Suspended solid (mg/l):** 50ml of samples through pre – weighted glass fibre paper dried for 30 minutes and weighed again. The suspended solid content of the sample is the difference in the weight of filters. For a given sample location, the experiments were repeated three times and average reading were taken [16].

4. DATA ANALYSIS

SPSS program version 17.0 was used for statistical analysis. Mean values of each parameter measured was compared using Duncan`s multiple range test. The statistical inference was made at 0.05 (5%) level of significance.

5. RESULTS AND DISCUSSION

Performance of the Paddle–Wheel and Spiral Aerators

Locally developed Prototype of aerators are presented in plates 1 and 2. The predictive equations indicated that the oxygen transfer rate (OTR) standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) were found to decrease with increase in the volume of water.

The oxygen transfer rate, standard oxygen transfer rate and standard aerator efficiency for paddle–wheel aerator ranged from 3.08–8.19 (hr^{-1}); 1.09–1.30 (kgO_2/hr), and 1.13–1.34 (kgO_2/KWhr) respectively. While for the spiral aerator ranged from 4.46–8.22 ($hr^{-}1$); 1.10–1.32 (kgO_2/hr), and 1.18–1.36 (kgO_2/KWhr) respectively. The result agreed with Boyd (1998) that the standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) of the aerators were inversely proportional to the volume of water, other parameters remain constant.

The summary of the results of the performance evaluation of the developed aerators are presented in Table 1. This finding differs slightly from evaluations made by other investigators.

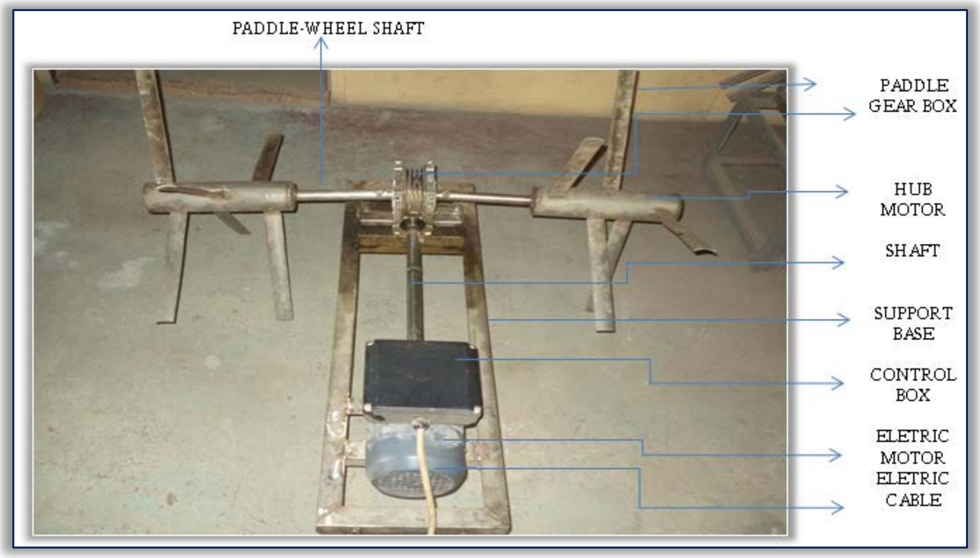

Plate 1: Developed Paddle–Wheel aerator

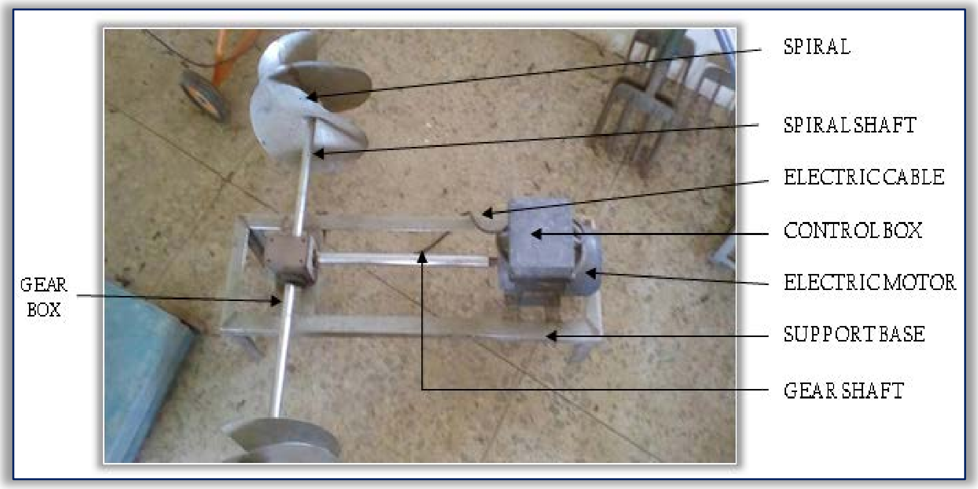

Plate 2: Developed Spiral Aerator

Table 1. Summary of Oxygen transfer coefficient, Standard Oxygen Transfer Rate (SOTR) and Standard Aeration Efficiency (SAE) for the Paddle wheel aerator and Spiral Aerator

	Paddle – While Aerator			Spiral Aerator		
Vol. of water (cm^3)	Oxygen transfer Coef. KLa (hr^{-1})	SORT (kgO_2hr^{-1})	SAE ($kgO_2KW^{-1}hr^{-1}$)	Oxygen transfer Coef. KLa (hr^{-1})	SORT (kgO_2hr^{-1})	SAE ($kgO_2KW^{-1}hr^{-1}$)
1	8.19	1.30	1.34	8.22	1.32	1.36
2	7.20	1.29	1.30	8.11	1.30	1.33
3	6.65	1.25	1.27	7.19	1.28	1.30
4	5.56	1.21	1.23	6.25	1.25	1.26
5	4.65	1.19	1.19	5.56	1.21	1.23
6	4.18	1.11	1.17	5.42	1.19	1.20
7	3.52	1.10	1.15	4.74	1.11	1.19
8	3.08	1.09	1.13	4.46	1.10	1.18

Result of [17] evaluates indicated that standard oxygen transfer rate and standard aerator efficiency for twenty four types of the paddle wheel aerators ranged from 1.9–8.5 (kg O_2/hr) and 1.2–5.2 (kg O_2/KWhr) respectively, while standard oxygen transfer rate and standard aerator efficiency for twenty types of the spiral aerators ranged from 2.1–9.8 (kg O_2/hr) and 2. 1–7.8 (kgO_2/KWhr) respectively. Evaluation of [7–8] indicated that standard oxygen transfer rate and standard aerator efficiency for six paddle wheel aerators ranged from 5.2–18.5 (kg O_2 hr^{-1}) and 2.6–3.0 (kg O_2KW^{-1} hr^{-1}) respectively, while for that standard oxygen transfer rate and standard aerator efficiency for five spiral aerators ranged from 6.2–19.5 (kgO_2/hr) and 5.2–15.5 (kgO_2/KWhr) respectively. These differences may be due to different size of paddle, numbers of paddle, arrangement of the paddle on the hub, speed of the paddle wheel aerator, the depth of operation, types of prime mover, power used, geometrical of basin and physicochemical properties of water.

Plate 3: Mounted paddle wheel aerator for operation

The results indicated that the effectiveness of the designed prototype machine depends on the volume of water (Table 2). For paddle–wheel aerator at $2m^3$ or less volume, the prototype machine provided adequate supply and uniform and equal distribution and mixing of dissolved oxygen in the system (Table 2) $2m^3$ to $5m^3$ supplied and provide mixing of dissolved oxygen at non–uniformity of dissolved oxygen in entire volume. At pond water volume above $5m^{3,}$ dead zones and oxygen stratification occurred. While for spiral aerator at $3m^3$ or less volume of water, the prototype machine developed provided adequate supply and uniform and equal distribution and mixing of dissolved oxygen in the system (Table 2) $3m^3$ to $6m^3$ supplied and provide mixing of dissolved oxygen at non–uniformity of dissolved oxygen in entire volume. At pond water volume above $6m^{3,}$ dead zones and oxygen stratification occurred. The results indicated that spiral aerator performed better that paddle–wheel aerator because it achieved higher overall oxygen–transfer coefficient, standard oxygen transfer rate and standard aerator efficiency at the same volume of water, speed, power and depth of operation. The difference is attributed to blade configuration between the paddle–wheel and spiral aerators. From this result of the developed prototype performance evaluation and analysis, machinery extrapolation design development can be carried out for pond water volume in multiples of 2m3 or 3 m^3 pond water for paddle–wheel and spiral aerators respectively.

Table 2. The effectiveness level, range and restrictive feature of the Paddle wheel aerator and spiral aerator

Aerator Type	Water Volume range (cm^3)	Effectiveness Level	Restrictive Feature
Paddle–Wheel	≤ 2	High	Adequate supplied, equal distribution and mixing of dissolved oxygen within the system
	2 – 5	Medium	Supplied and provide mixing of dissolved oxygen at non–uniformity in the system
	> 5	Low	Dead zone and oxygen stratification occurred
Spiral	≤ 3	High	Adequate supplied, equal distribution and mixing of dissolved oxygen within the system
	3 – 6	Medium	Supplied and provide mixing of dissolved oxygen and non–uniformity in the system
	> 6	Low	Dead zone and oxygen stratification occurred

Impacts of the Aerators on Concentration of the Catfish Effluents

The impacts of the aerators on the concentration of the catfish effluent are presented in Figures 1–6 respectively.

– The impacts of aerators on concentration of suspended solids

Percentage reduction in the total suspended solids (TSS) between paddlewheel and spiral aerators were presented in Figure 1. The percentage reduction in the total suspended solids was higher with the paddle wheel than that of spiral. The percentage mean difference in reduction of concentration of suspended solids between paddle–wheel and spiral was 18.4%. This study support [10] that aeration can remove certain dissolved gasses and minerals through oxidation. The results were significant ($P \geq 0.05$) difference between percentage mean reduction in the total suspended solids between paddle–wheel and spiral aerators at the level of dilution ratio. The difference may be attributed to more turbulent actions created by the spiral aerator, nature of the total suspended particles (organic matter content) and blade configuration.

 – The impacts of aerators on concentration of Nitrogen (mg/l)

Percentage increase in the nitrogen between paddle wheel and spiral aerators were presented in Figure 2. The percentage reduction in the nitrogen was lower with the paddle wheel than that of spiral. The percentage mean difference in reduction of concentration of nitrogen between paddle–wheel and spiral was 5.1%. This study support [10] that aeration can remove certain dissolved gasses and minerals through oxidation. The results were significant (P ≥ 0.05) difference between percentage mean reduction in the nitrogen between paddle–wheel and spiral aerators at the level of dilution ratio. The difference may be attributed to more turbulent actions created by the spiral aerator, nature of the total dissolved particles (organic matter content) and blade configuration

 – The impacts of aerators on concentration of Ammonia (mg/l)

Percentage increase in the ammonia between paddle wheel and spiral aerators were presented in Figure 3. The percentage reduction in the ammonia was lower with the paddle wheel than that of spiral. The percentage mean difference in reduction of concentration of ammonia between paddle–wheel and spiral was 7.4 %. This study support [10] that aeration can remove certain dissolved gasses and minerals through oxidation. The results were no significant (P ≥ 0.05) difference between percentage mean reduction in the ammonia between paddle–wheel and spiral aerators at the level of dilution ratio.

 – The impacts of aerators on concentration of nitrite (mg/l)

Percentage reduction in the nitrite between paddle wheel and spiral aerators were presented in Figure 4. The percentage reduction in the nitrite was lower with the paddle wheel than that of spiral. The percentage mean difference in increase of concentration of nitrite between paddle–wheel and spiral was 1.7%. This study support [10] that aeration can remove certain dissolved gasses and minerals through oxidation. The results were no significant (P ≥ 0.05) difference between percentage mean reduction in the nitrite between paddle–wheel and spiral aerators at the level of dilution ratio.

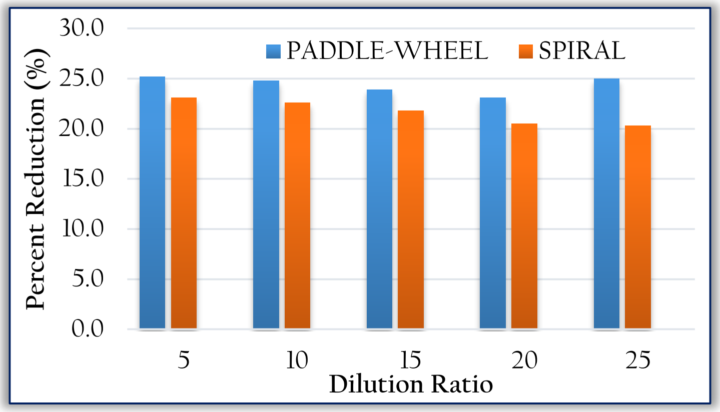

Figure 1. The bar chart shown the percentage reduction of concentration of suspended solids

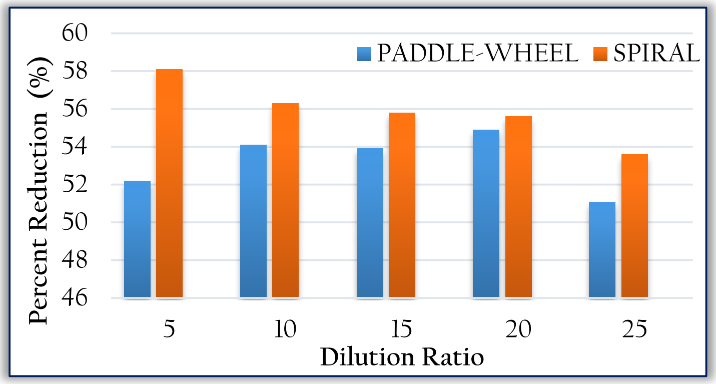

Figure 2. The bar chart shown the percentage reduction of concentration of Nitrogen

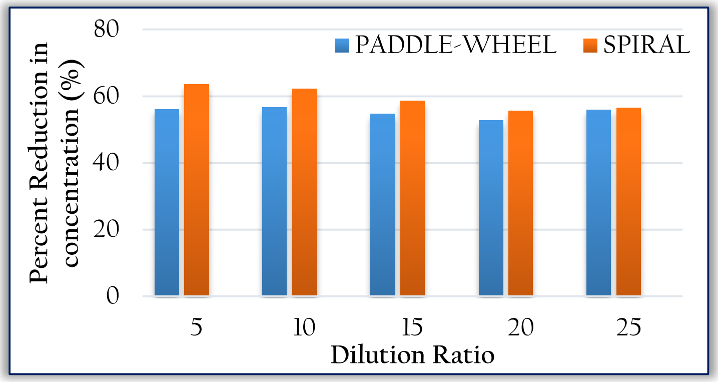

Figure 3. The Bar Chart Shown the Percentage reduction of Concentration of Ammonia

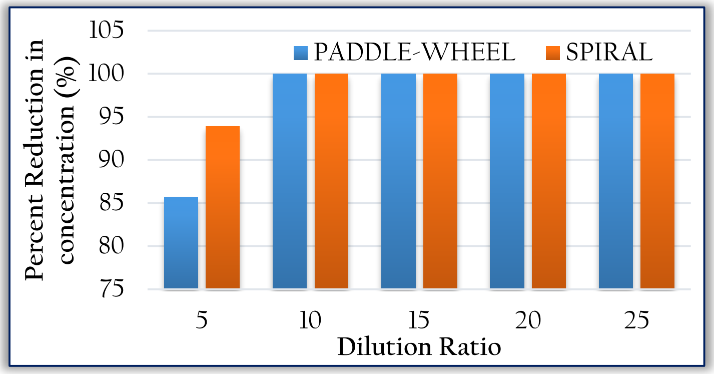

Figure 4. The Bar Chart Shown the Percentage Reduction of Concentration of Nitrite

– The impacts of aerators on concentration of nitrate (mg/l)

Percentage increase in the nitrate between paddle wheel and spiral aerators were presented in Figure 5. The percentage increase in the nitrate was lower with the paddle wheel than that of spiral. The percentage mean difference in increase of concentration of nitrate between paddle–wheel and spiral was 5.9 %. The results were no significant (P ≥ 0.05) difference between percentage mean increase in the nitrate between paddle–wheel and spiral aerators at the level of dilution ratio.

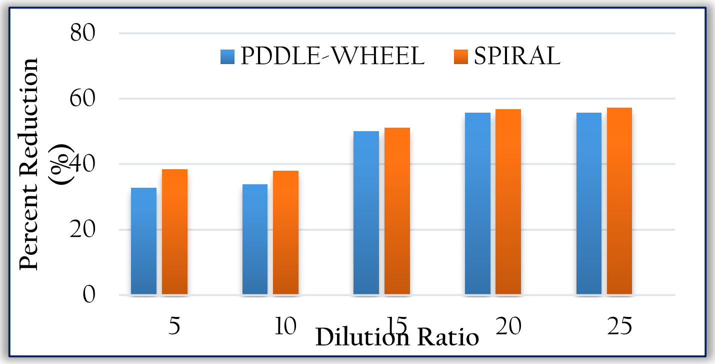

Figure 5. The Bar Chart Shown the Percentage Increase of Concentration of Nitrate

– The impacts of aerators on concentration of phosphorus (mg/l)

Percentage reduction in the phosphorus between paddle wheel and spiral aerators were presented in Figure 2. The percentage reduction in the phosphorus was lower with the paddle wheel than that of spiral. The percentage mean difference in increase of concentration of phosphorus between paddle–wheel and spiral was 1.0 %. This study support [10] that aeration can remove certain dissolved gasses and minerals through oxidation. The results were no significant (P ≥ 0.05) difference between percentage mean reduction in the phosphorus between paddle–wheel and spiral aerators at the level of dilution ratio.

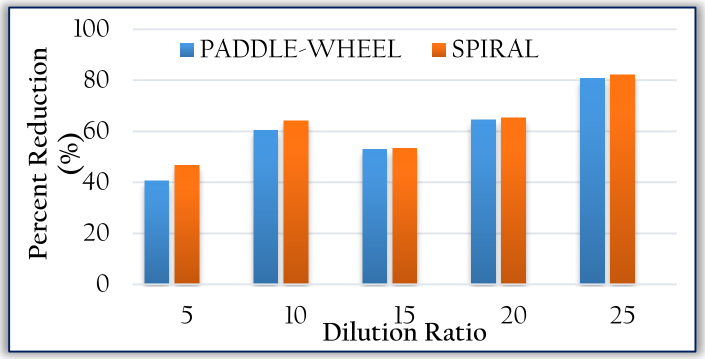

Figure 6. The Bar Chart Shown the Percentage Reduction of Concentration of Phosphorus

6. CONCLUSIONS

From the above mentioned study, it observed that the effectiveness of the paddle–wheel and spiral aerators and its impacts on catfish effluent were assessed. Results from the study indicate that:

– The machines (paddle–wheel and spiral aerators) were pumped in circle and there was dissolved oxygen gradient in basin.
– The paddle–wheel aerator is effective and efficient at water volume equal to or less than 2m^3 pond water, while spiral aerator is effective and efficient at water volume equal to or less than 3 m^3 pond water
– Spiral aerator performed better that paddle–wheel aerator because it achieved higher overall oxygen – transfer coefficient, standard oxygen transfer rate and standard aerator efficiency at the same volume of water, speed, power and depth of operation
– The machines reduce certain dissolved gasses and minerals through oxidation
– Spiral aerator performance better that paddle–wheel aerator on catfish effluent reduction
– Blade configuration is the main factor responsible to difference in their performance between spiral and paddle wheel aerators.
– Aeration enhances reductions in the concentration of nitrogen, ammonia, nitrite, phosphorus
– Reduction in the concentration not depended on dilution ratio and purely aerobic process.
– The machines were found effective in the water quality improvement
– The effect of aerator on evaporation in the pond should be investigate
– The effect of speed on performance of aerator should be investigated
– The effect of depth of operation on efficiency of aerator should be investigated

Acknowledgements

Part of this study that leads to this publication was sponsored by the tertiary education trust fund of Nigeria.

References

[1] Ajana A.M., "Overview of highlight and problems of fisheries extension in Nigeria Agriculture" Nigeria`s Pioneer Agriculture News Reporting and Trade Promotion Magazine Vol.4 No.1: pp. 27–32, 2002
[2] Adamu B.,"Trade and Investment opportunity in Agriculture" Paper presented at the India–Africa Agric. Food Submit in New Delhi. pp.142 – 148, 2007.

[3] Adekoya B.B., Ayansanwo A.A., Idowu T.O., Kudoro O.A. and Salisu A.A., "Inventor of Fish Hatcheries in Ogun State" .Ogun State Agricultural Development Programme (ADP), Abeokuta. pp. 98 – 101, 10 – 12th April 2006
[4] Boyd C.E., "Guidelines for Aquaculture Effluent Management at the Farm level" Aquaculture, Vol. 226: pp. 101–112, 2003
[5] Magmedov V., " Constructed wetlands for low cost treatment" Available at http://www.constructedwetlands.org/cw/index.cfm, 2002
[6] Boyd C.E., "Water quality standards on Dissolved Oxygen" Global Aquaculture Advocate Vol. 4, No 6: pp. 70–72, 2001
[7] Boyd C.E. and Ahmad T., "Evaluation of Aerators for Channel Catfish Farming" bulletin 584, Alabama Agricultural Experiment Station, Auurn University, Alabama. pp. 52, 1997
[8] Ahmand T. and Boyd C.E., "Design of small paddle wheel aerator" Aqua cultural Engineering. New Delhi. Pp. 55 – 69, 1988
[9] Omofunmi O.E., Adewumi J.K., Adisa A.F. and Alegbeleye W.O., "Performance Evaluation of Developed Paddle aerator on Catfish Effluents in Lagos State, Nigeria" Journal of Agricultural Science and Environment, 16 (1): pp. 75 – 85, 2016
[10] Igib P., Agus S. and Ahmad A.S., "Design optimization of solar powered aeration system for fish pond in Sleman Regency" Yogyakarta by HOMER software. Energy Procedia, 32(1): pp. 90 – 98, 2013
[11] Tucker C.S., "Pond Aeration" Southern Regional Aquaculture Center Fact Sheet 3700. United States: pp. 532, 2005
[12] Tucker C.S. and Robinson E.H., "Channel Catfish Farming Handbook" New York: Nostrand Reinhold: pp. 342 – 349, 1990
[13] Schwartz M.F. and Boyd C.E., "Channel catfish pond effluents" Prog. Fish culture, 56:273–.281, 2013
[14] Boyd C.E., "Dissolved oxygen concentrations in pond aquaculture" Global aquaculture advocate. Ph.D. diss., Fisheries and Allied Aquacultures Dept., Auburn Univ. Alabama; pp. 342 – 348, 2010
[15] Omofunmi O.E., Adewumi J.K., Adisa A.F. and Alegbeleye W.O., "Development of a Paddle–Wheel Aerator for small and medium Farmers in Nigeria" Journal of Agricultural, Mechanization in Asia, Africa and Latin America (AMA), 48 (1): pp. 22– 26, 2017
[16] American Public Health Association (APHA)., "Standard Methods for the Examination of Water and Wastewater" 16th and 17th Eds. Washington, DC; American Water Works Association, Water Control Federation, 2005
[17] Moore J.M. and Boyd C.E., "Design and performance of paddle wheel aerators" Aquacultural Engineering. pp. 39 – 62, 1992

ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665